Neutron and x-ray sources

Rob McQueeney

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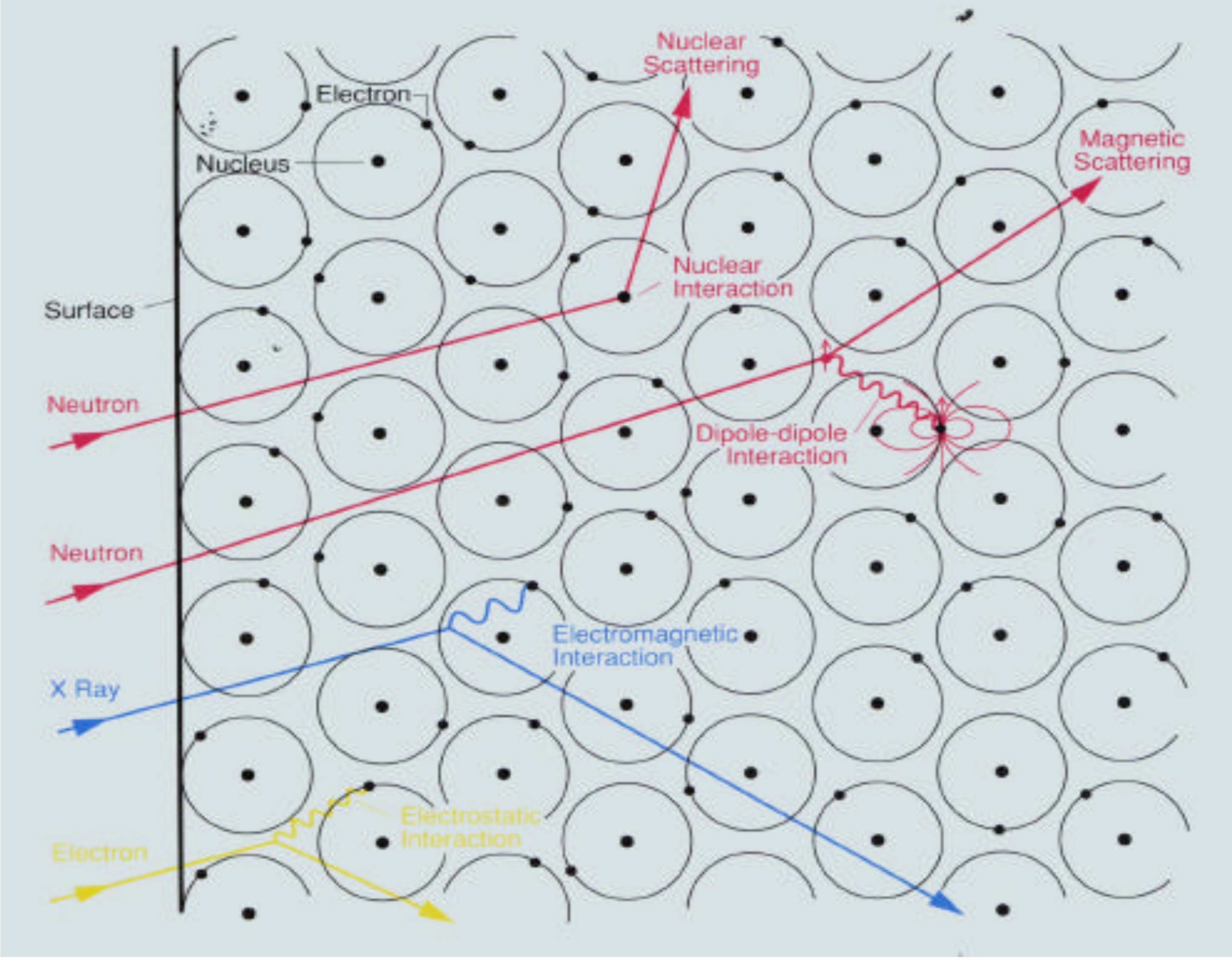
IOWA STATE UNIVERSITY

Different probes



Different probes

	NEUTRONS	X-RAYS	ELECTRONS
Wavelength range	0.4 - 10 Å	0.1 - 5 Å	0 .04 - 0.2 Å
Energy range	0.001 - 0.5 eV	3000 - 100000 eV	6000 - 120000 eV
Cross-section	10^{-25} barns	10^{-25} Z^2 barns	~10^{-22} barns
Penetration depth	~ cm	~ μm	~ nm
Typical flux	10^{11} s^{-1} m^{-2}	10^{24} s^{-1} m^{-2}	10^{26} s^{-1} m^{-2}
Beam size	mm-cm	μm-mm	nm-μm
Typical sample	Any bulk sample	Small crystals, powders, surfaces	Surfaces, thin films, grains, gases
Techniques	Diffraction Inelastic scattering Reflectivity	Diffraction Photon absorption Photoemission Inelastic scattering	Microscopy Diffraction Emission spectroscopy EELS
Phenomena	Magnetic/crystal structures collective excitations (phonons, spin waves) electronic excitations (crystal-field, spin-orbit)	Crystal structures, electronic transitions (photoemission, absorption),	microstructure crystal structures electronic transitions

Cross-sections

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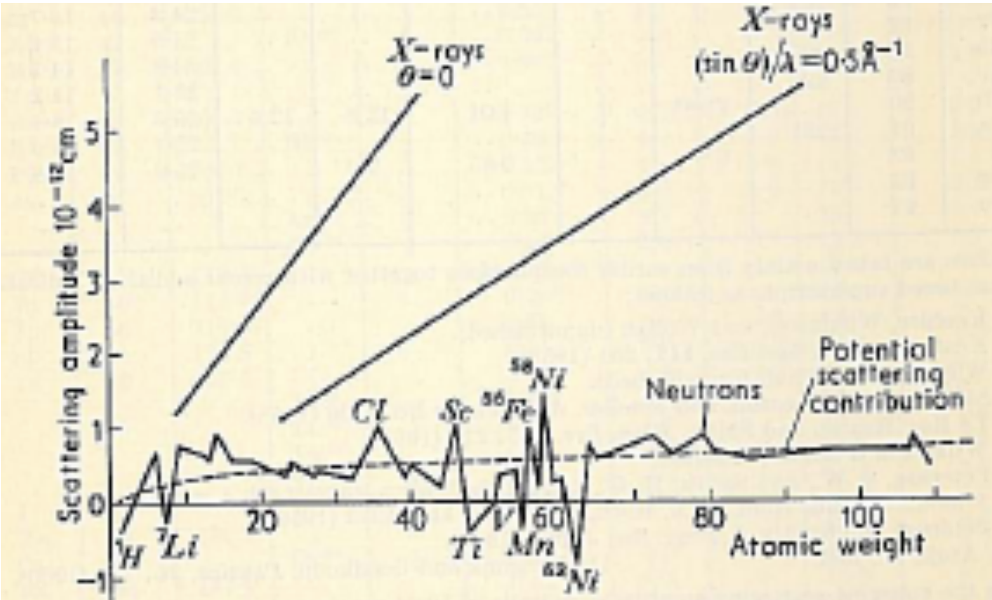


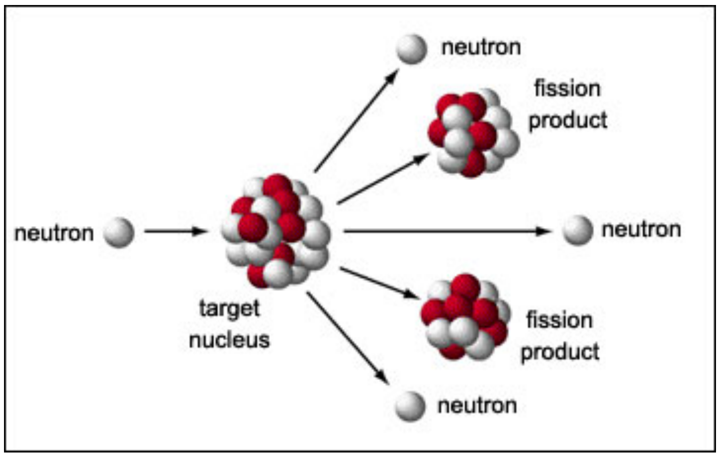
- **Neutrons**
  - Random with Z
  - Depends on isotope
  - Depends on nuclear spin
  - Absorption can be problem

	Abundance (%)	Cross-section (bn)	Absorption (bn)
Gd	---	180	49700
152Gd	0.2	13	735
154Gd	2.1	13	85
155Gd	14.8	66	61100
156Gd	20.6	5	1.5
157Gd	15.7	1044	259000
158Gd	24.8	10	2.2
160Gd	21.8	10.52	0.77

Producing neutrons

Fission

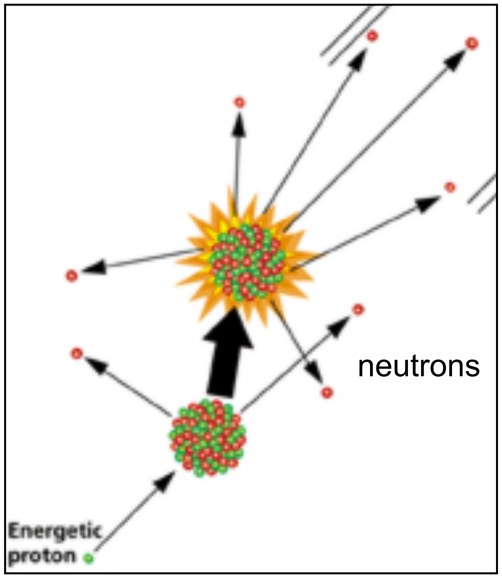
Nuclear reactor



Moderators →Cold-Thermal

Spallation

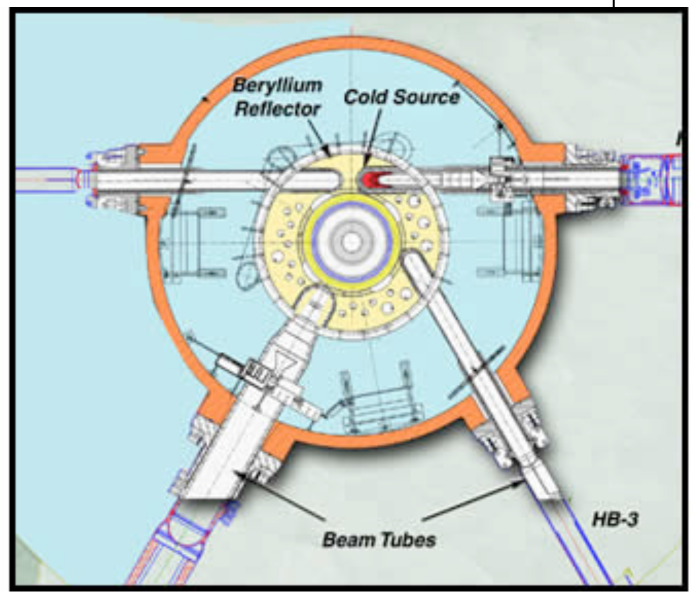
Particle accelerator

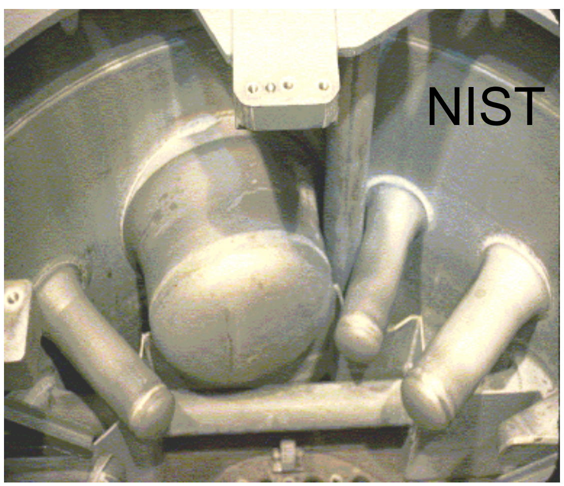


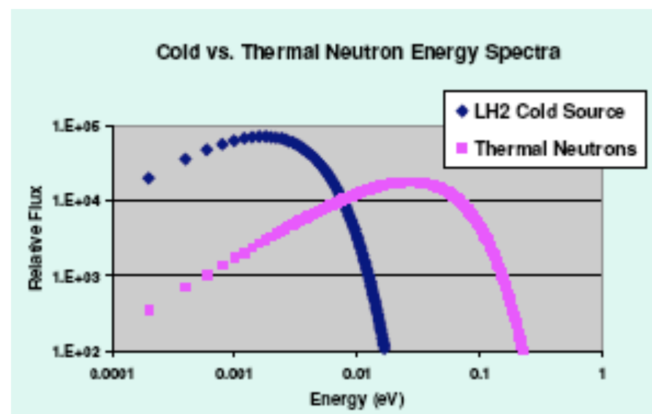
Moderators →Cold-Epithermal

Neutrons by reactor fission

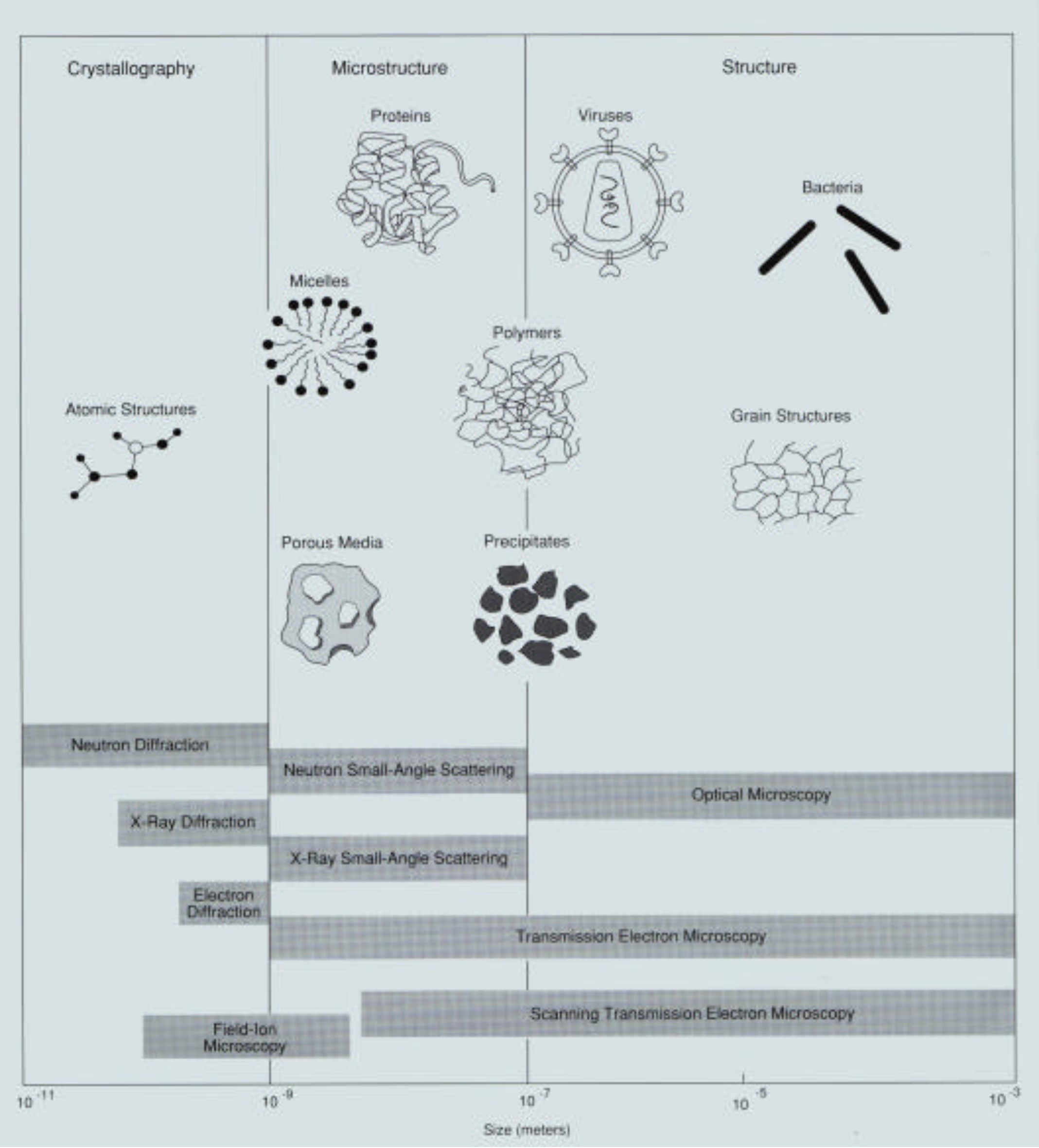
High flux isotope reactor - ORNL







Length scales



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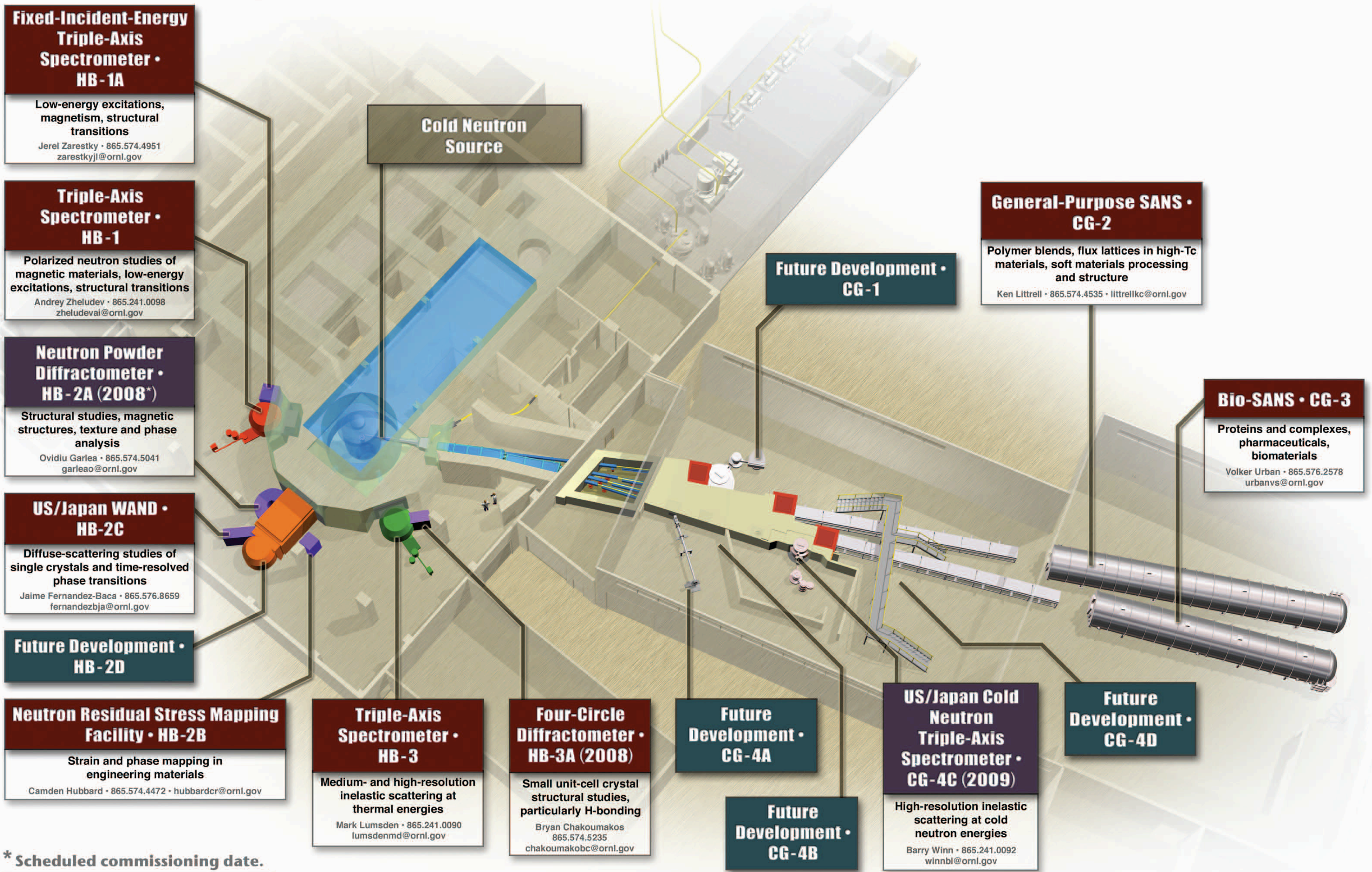
High Flux Isotope Reactor at Oak Ridge National Laboratory

The United States' highest flux reactor-based source of neutrons for condensed matter research

ORY



* Scheduled commissioning date.

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In design or construction
Under consideration

07-G00244E/arm

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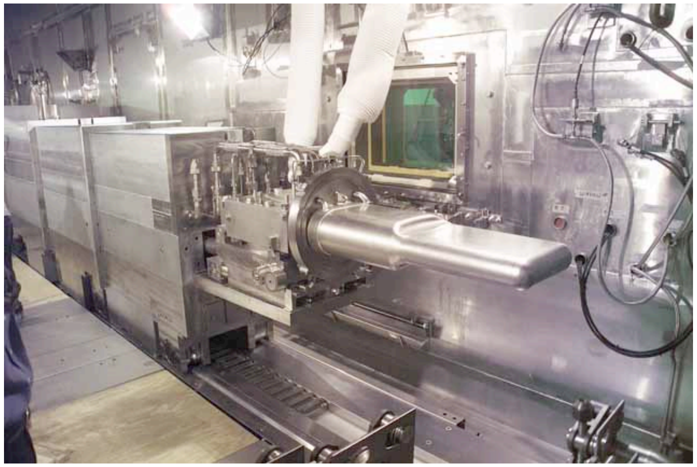
Oak Ridge National Laboratory

Neutron Sciences

Neutrons by pulsed spallation

Spallation Neutron Source (ORNL)

Target-moderator system



SNS liquid Hg target

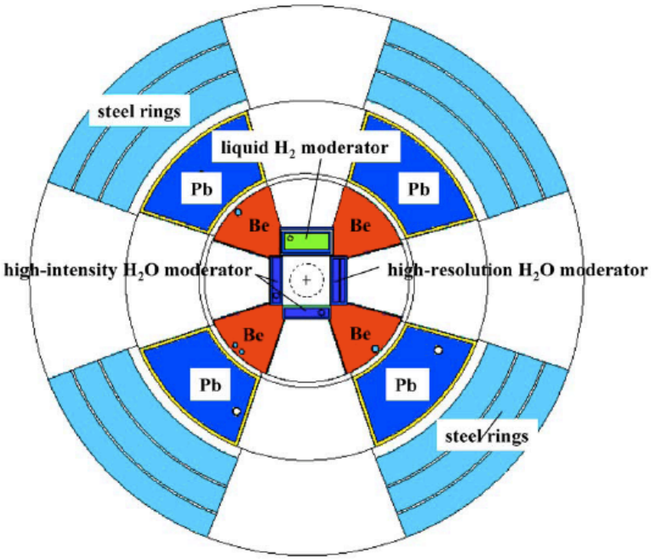
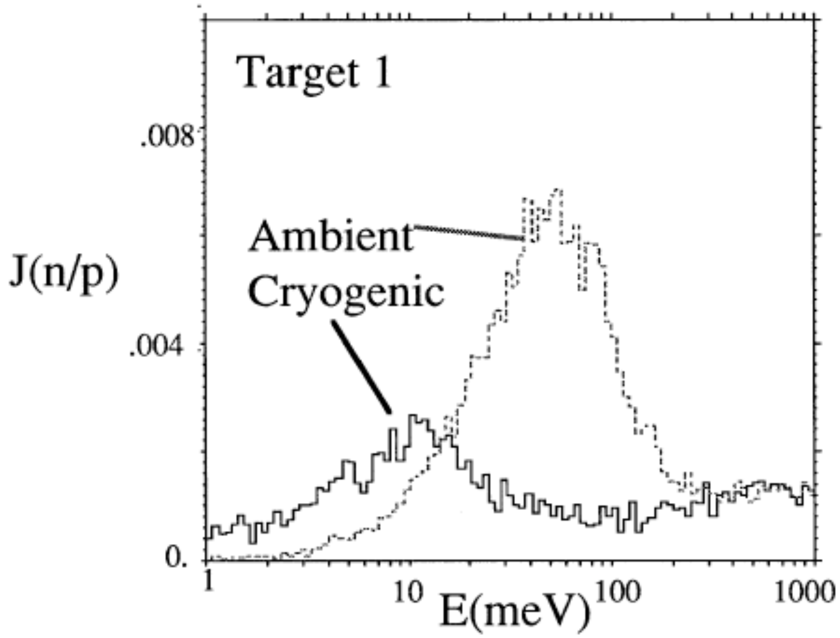
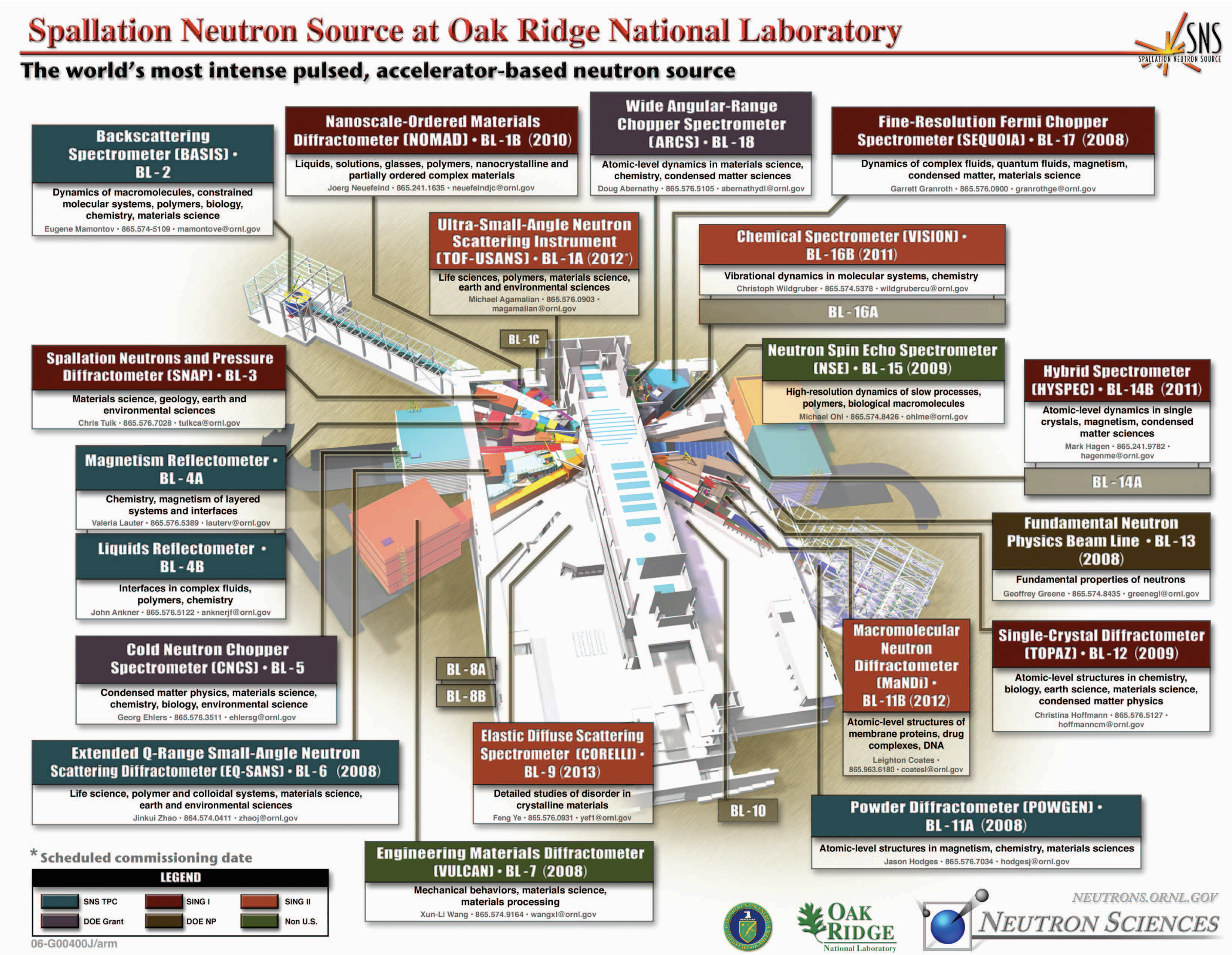


Fig. 3. Horizontal cross-section of the flux-trap moderators.




Spallation Neutron Source at Oak Ridge National Laboratory
The world's most intense pulsed, accelerator-based neutron source
SNS SPALLATION NEUTRON SOURCE
Backscattering Spectrometer (BASIS) • BL-2
Dynamics of macromolecules, constrained molecular systems, polymers, biology, chemistry, materials science
Eugene Mamontov • 865.574-5109 • mamontove@ornl.gov
Nanoscale-Ordered Materials Diffractometer (NOMAD) • BL-1B (2010)
Liquids, solutions, glasses, polymers, nanocrystalline and partially ordered complex materials
Joerg Neuefeind • 865.241.1635 • neuefeindjc@ornl.gov
Wide Angular-Range Chopper Spectrometer (ARCS) • BL-18
Atomic-level dynamics in materials science, chemistry, condensed matter sciences
Doug Abernathy • 865.576.5105 • abernathydl@ornl.gov
Fine-Resolution Fermi Chopper Spectrometer (SEQUOIA) • BL-17 (2008)
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Garrett Granroth • 865.576.0900 • granrothge@ornl.gov
Ultra-Small-Angle Neutron Scattering Instrument (TOF-USANS) • BL-1A (2012*)
Life sciences, polymers, materials science, earth and environmental sciences
Michael Agamalian • 865.576.0903 • magamalian@ornl.gov
Chemical Spectrometer (VISION) • BL-16B (2011)
Vibrational dynamics in molecular systems, chemistry
Christoph Wildgruber • 865.574.5378 • wildgrubercu@ornl.gov
BL-16A
BL-1C
Spallation Neutrons and Pressure Diffractometer (SNAP) • BL-3
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Chris Tulk • 865.576.7028 • tulkca@ornl.gov
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Hybrid Spectrometer (HYSPEC) • BL-14B (2011)
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Mark Hagen • 865.241.9782 • hagenme@ornl.gov
BL-14A
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Valeria Lauter • 865.576.5389 • lauterv@ornl.gov
Liquids Reflectometer • BL-4B
Interfaces in complex fluids, polymers, chemistry
John Ankner • 865.576.5122 • anknerjf@ornl.gov
Fundamental Neutron Physics Beam Line • BL-13 (2008)
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Cold Neutron Chopper Spectrometer (CNCS) • BL-5
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Georg Ehlers • 865.576.3511 • ehlersg@ornl.gov
BL-8A
BL-8B
Macromolecular Neutron Diffractometer (MaNDi) • BL-11B (2012)
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Leighton Coates • 865.963.6180 • coatesl@ornl.gov
Single-Crystal Diffractometer (TOPAZ) • BL-12 (2009)
Atomic-level structures in chemistry, biology, earth science, materials science, condensed matter physics
Christina Hoffmann • 865.576.5127 • hoffmanncm@ornl.gov
Extended Q-Range Small-Angle Neutron Scattering Diffractometer (EQ-SANS) • BL-6 (2008)
Life science, polymer and colloidal systems, materials science, earth and environmental sciences
Jinkui Zhao • 864.574.0411 • zhaoj@ornl.gov
Elastic Diffuse Scattering Spectrometer (CORELLI) • BL-9 (2013)
Detailed studies of disorder in crystalline materials
Feng Ye • 865.576.0931 • yef1@ornl.gov
BL-10
Powder Diffractometer (POWGEN) • BL-11A (2008)
Atomic-level structures in magnetism, chemistry, materials sciences
Jason Hodges • 865.576.7034 • hodgesj@ornl.gov
* Scheduled commissioning date
LEGEND
SNS TPC
SING I
SING II
DOE Grant
DOE NP
Non U.S.
Engineering Materials Diffractometer (VULCAN) • BL-7 (2008)
Mechanical behaviors, materials science, materials processing
Xun-Li Wang • 865.574.9164 • wangxl@ornl.gov
OAK RIDGE National Laboratory
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NEUTRON SCIENCES
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Powder diffraction

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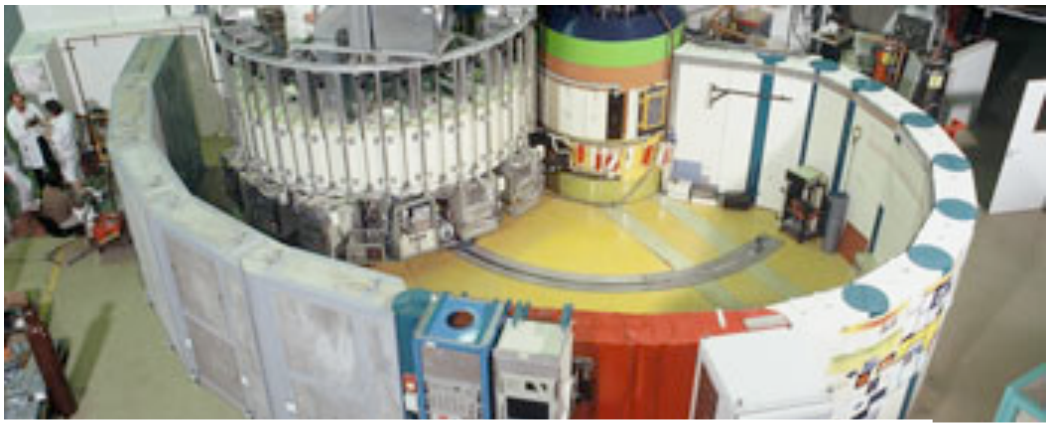
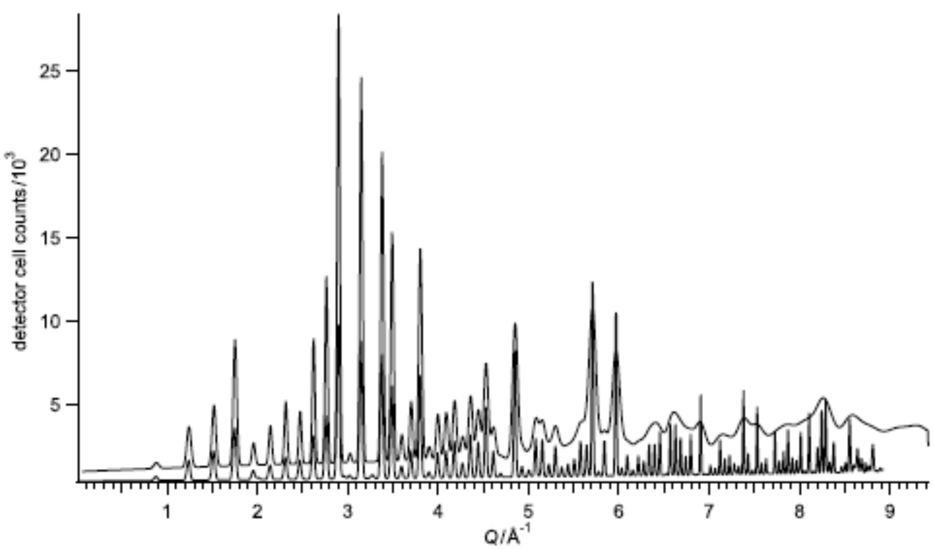
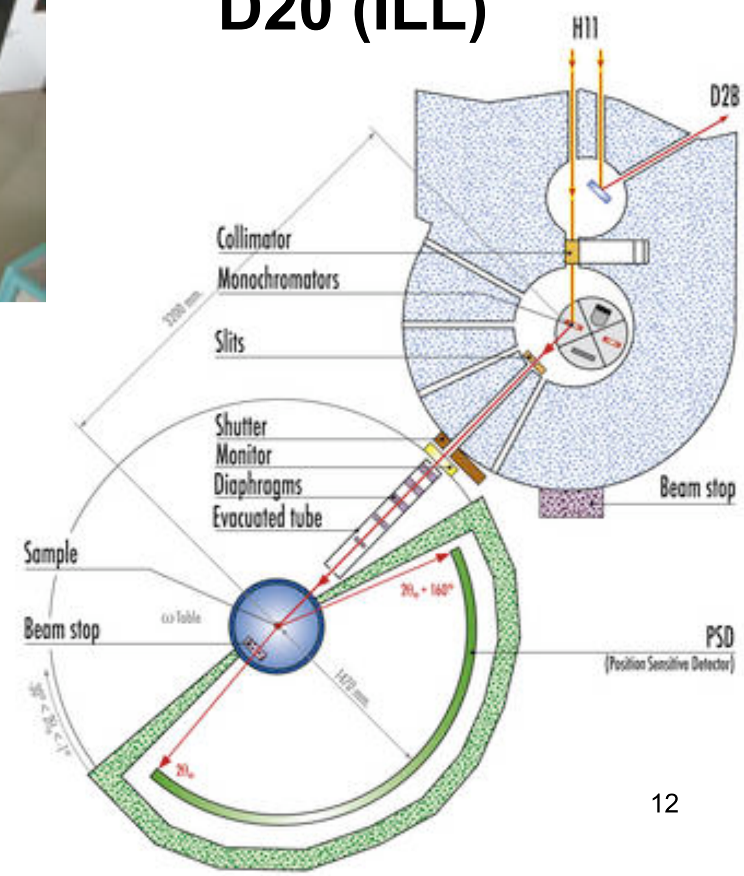
Determine the crystal structure

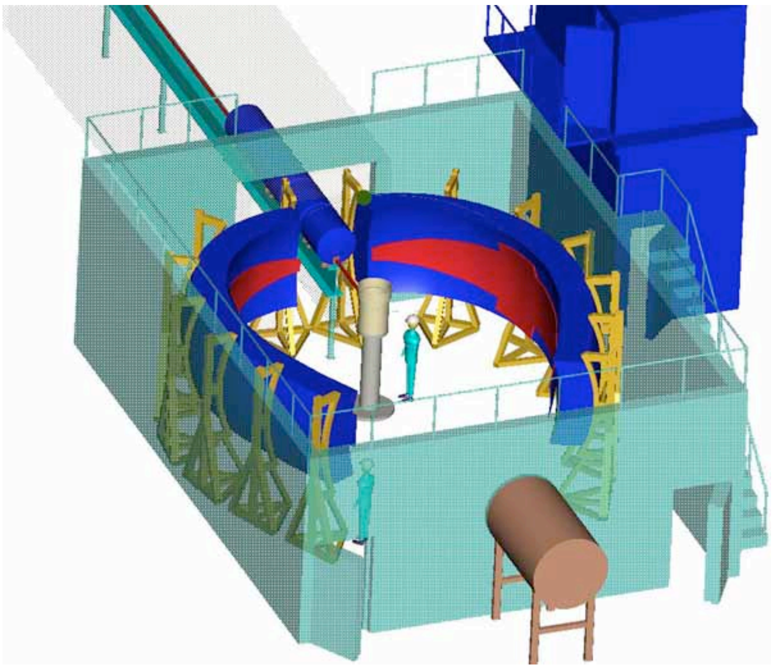




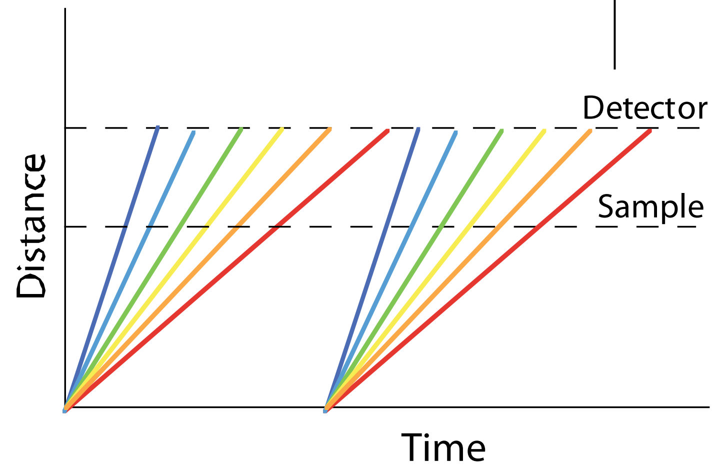
D20 (ILL)

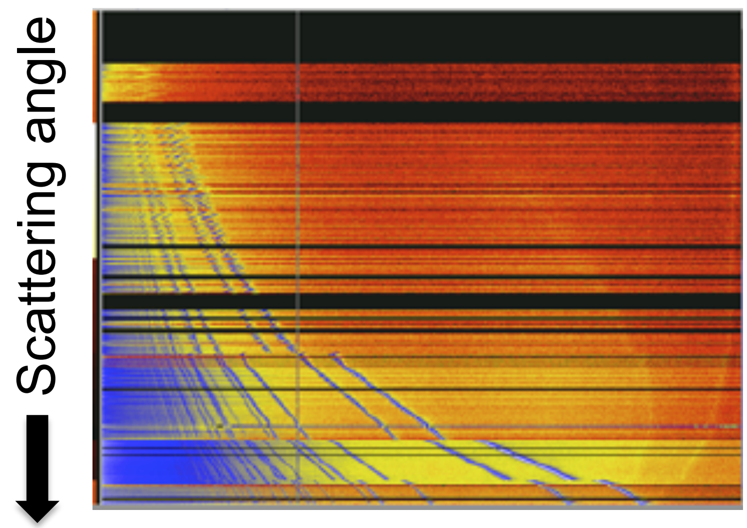


TOF powder diffraction



POWGEN @ SNS





Time-of-flight

$\tau = L/v = \lambda mL/h = 2mLd\sin\theta/h$

Single-crystal diffraction

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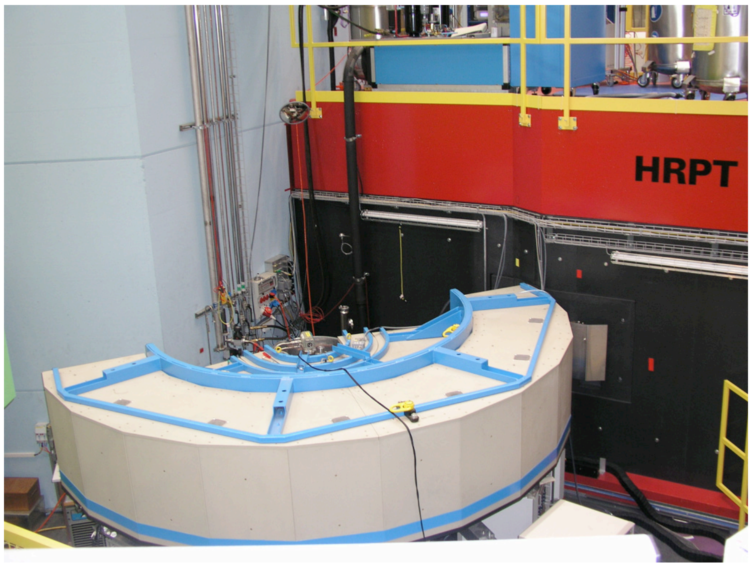
Single-crystal: more detail than powders
Wide angle diffraction: Get an overview of everything



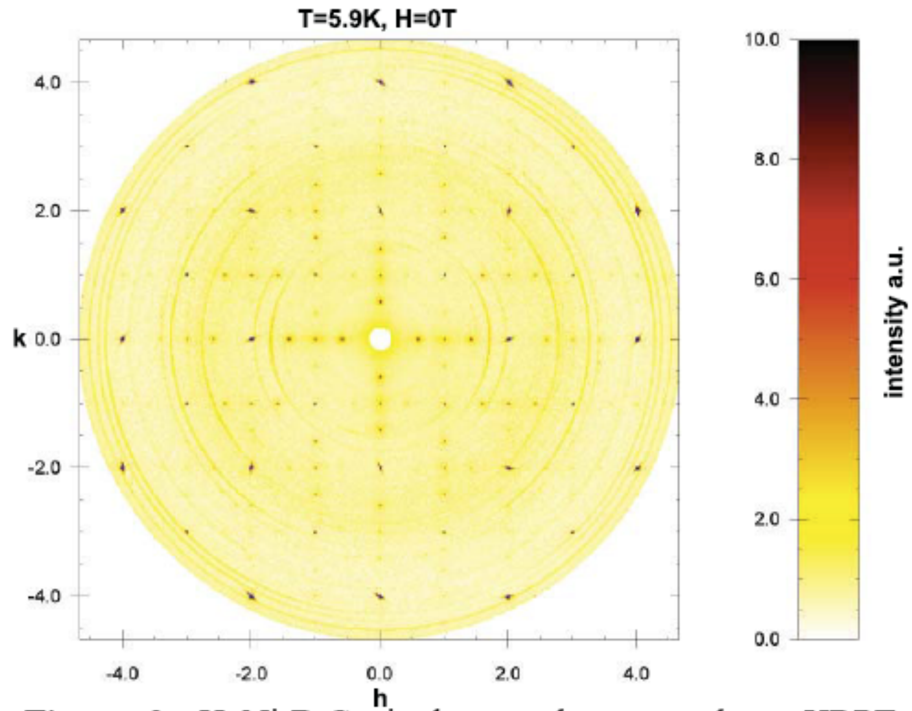
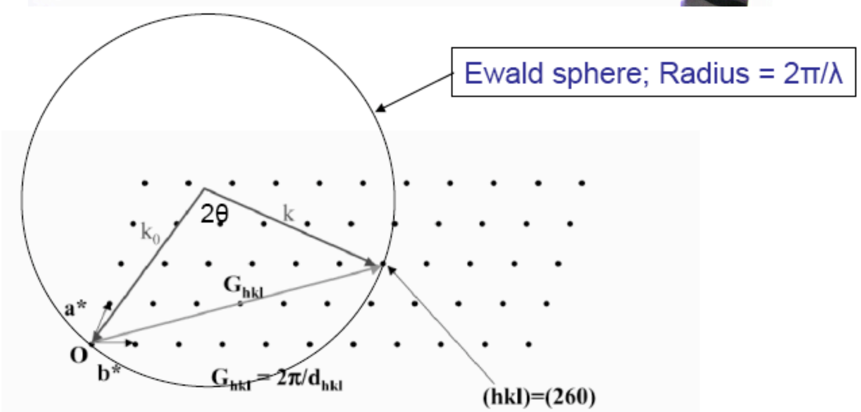


Figure 2: $HoNi_2B_2C$ single-crystal measured on HRPT



Incommensurate magnetism

TOF single-xtal diffraction

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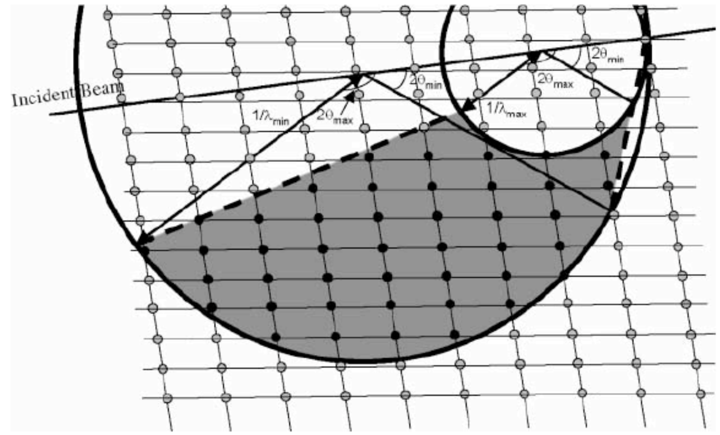
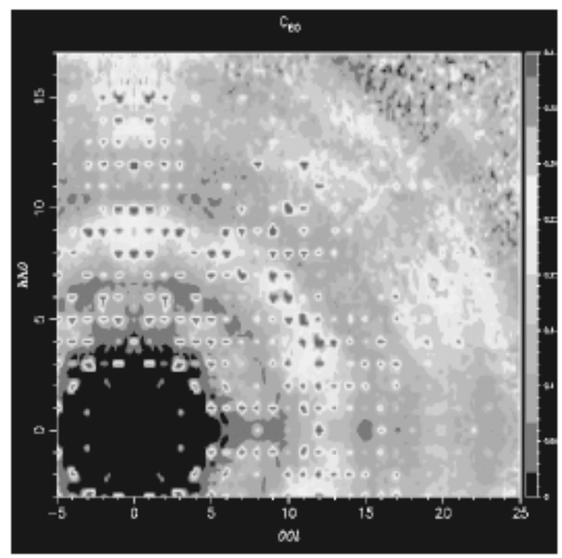
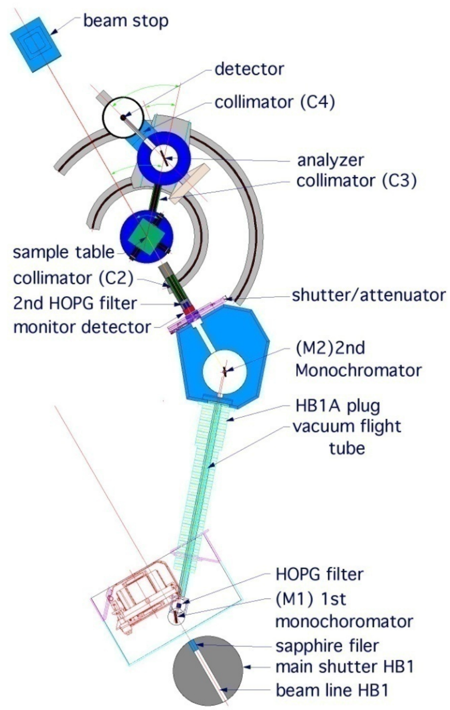


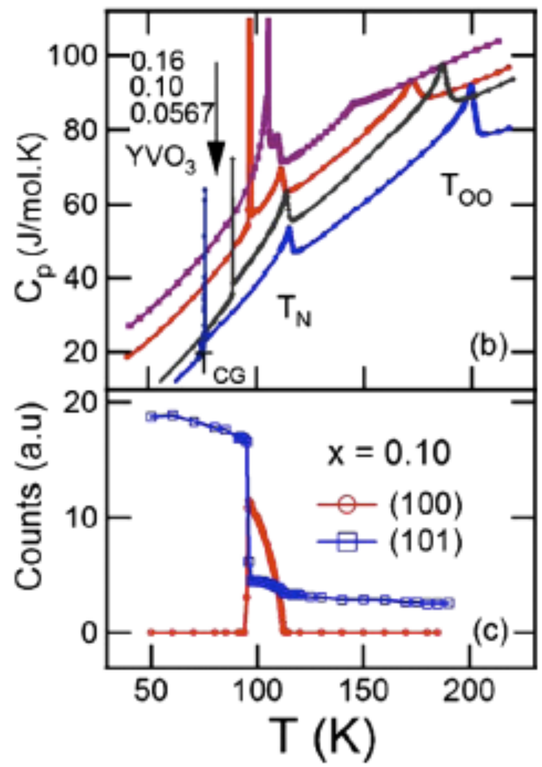


Single crystal diffraction

Triple-axis diffraction: focus in on specific points of interest

HB-1A 3-axis spectrometer





Orbital ordering in YVO_3

Production of x-rays

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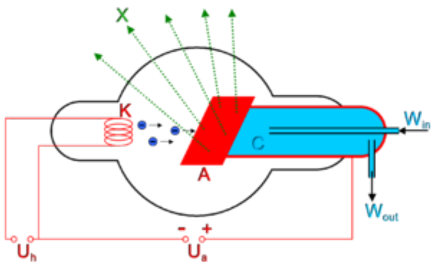
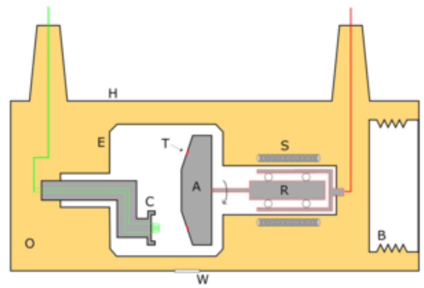
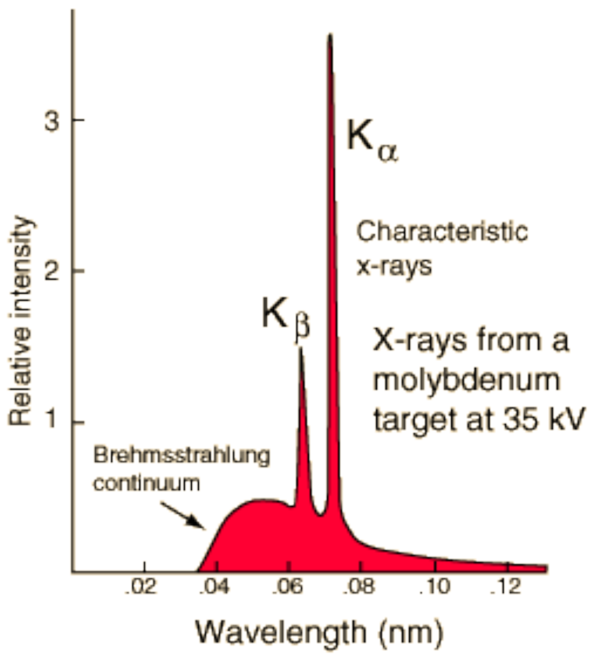


X-ray tube

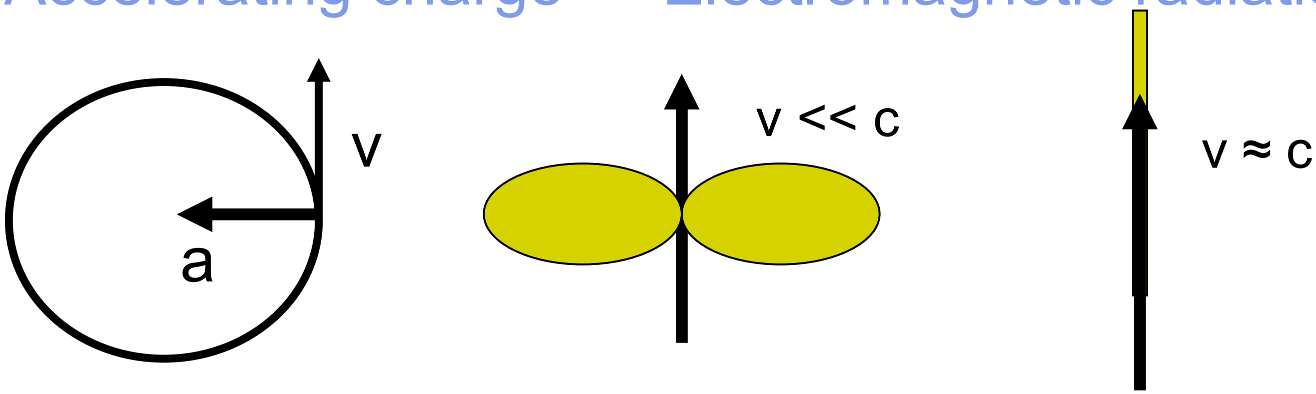


Rotating anode



How do we get x-rays?

- Static charge ---- Electric field
- Charge moving at constant v ---- Magnetic field
- Accelerating charge --- Electromagnetic radiation



Synchrotron radiation is
highly collimated
highly linearly polarized
highly brilliant
continuous wavelength distribution (beyond Cu, Mo, etc..)

Advanced Photon Source

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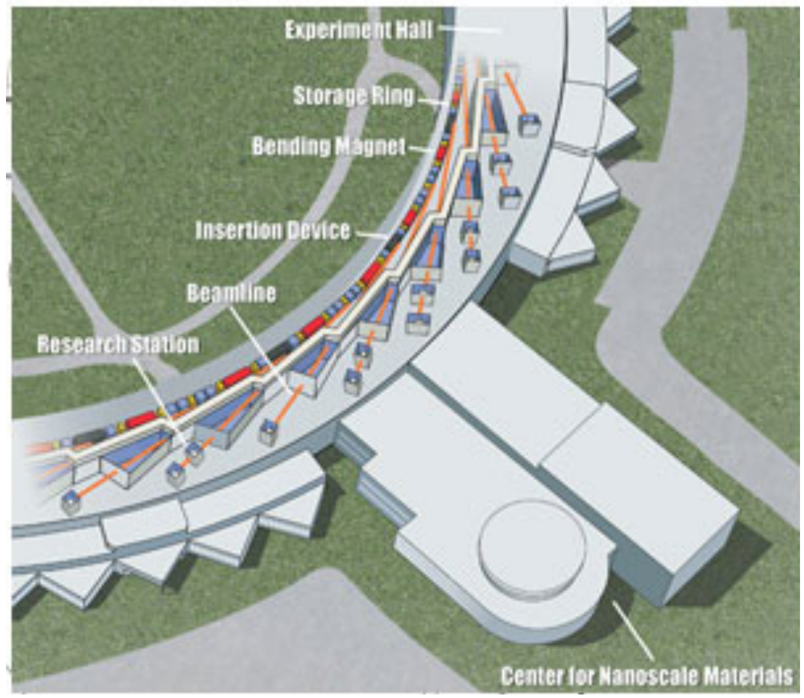
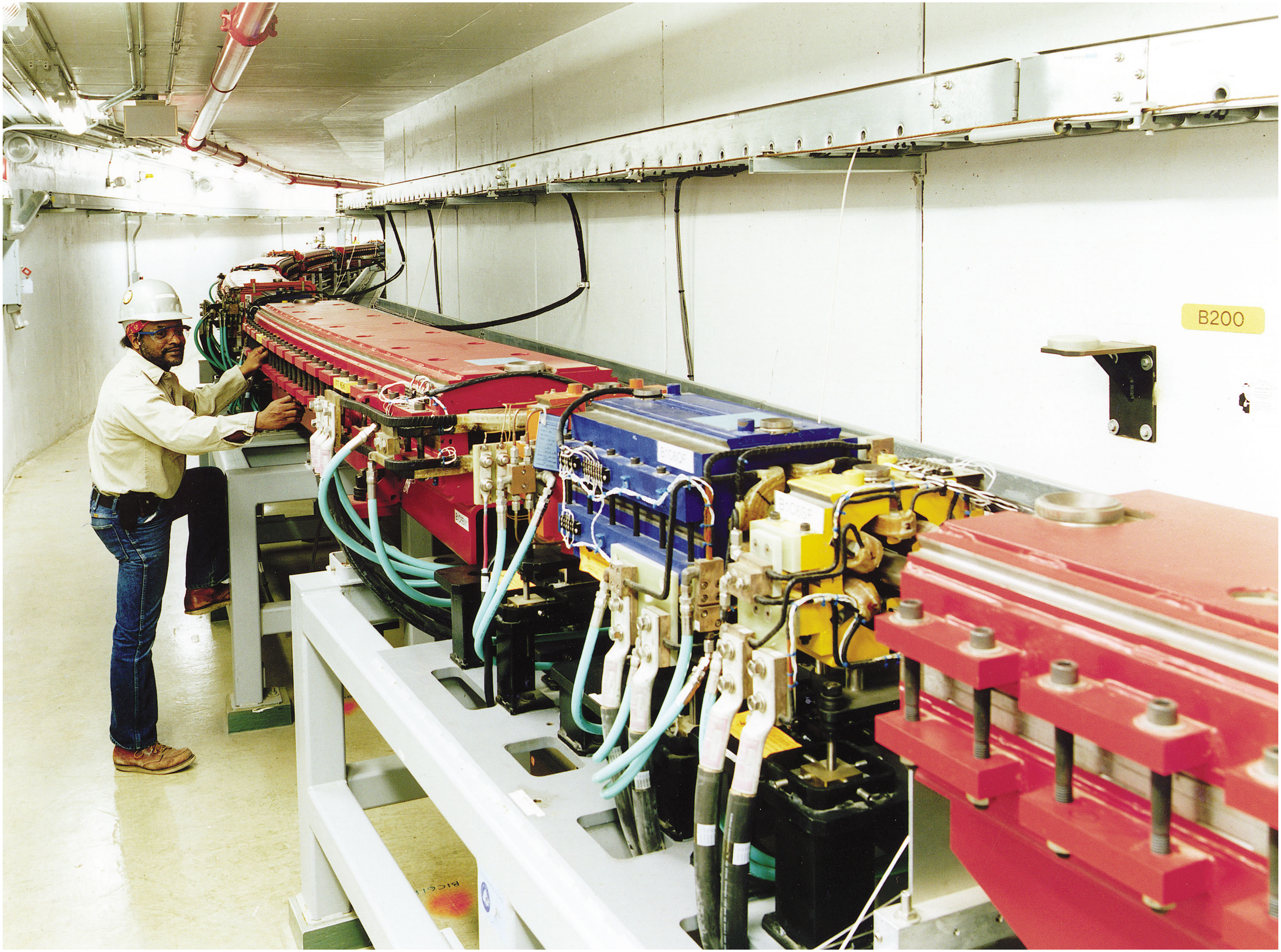
Synchrotron




B200

Insertion Devices

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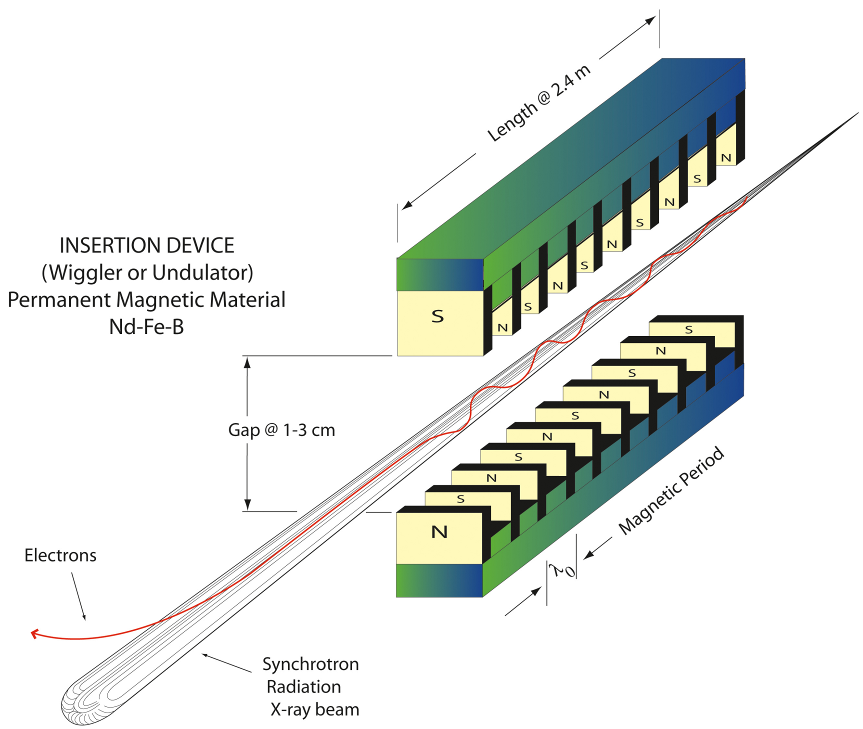

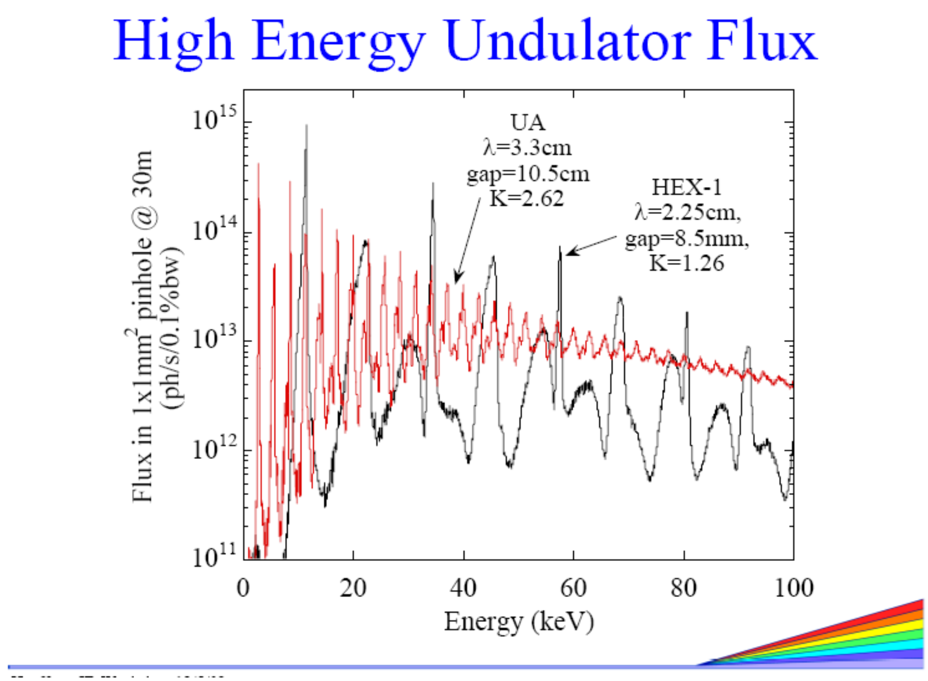

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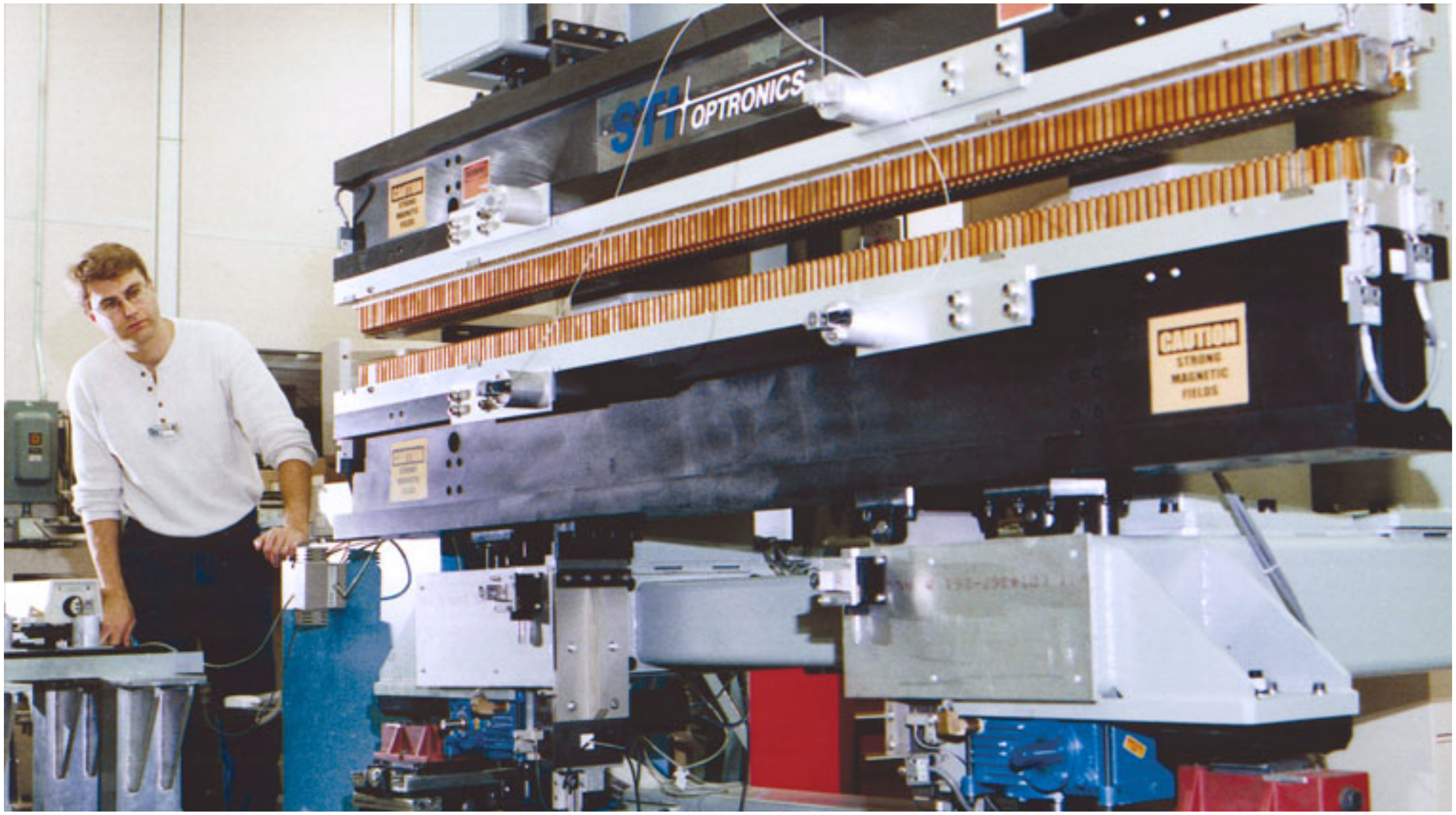

Main Undulator Line

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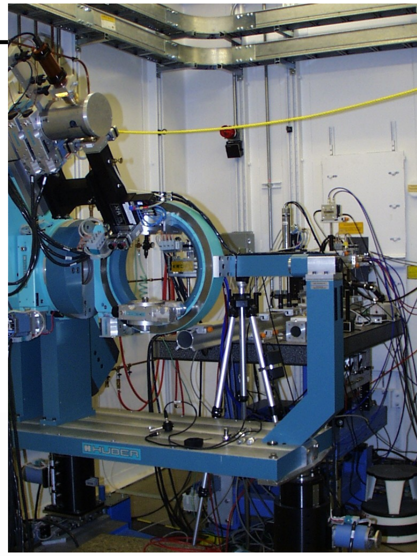

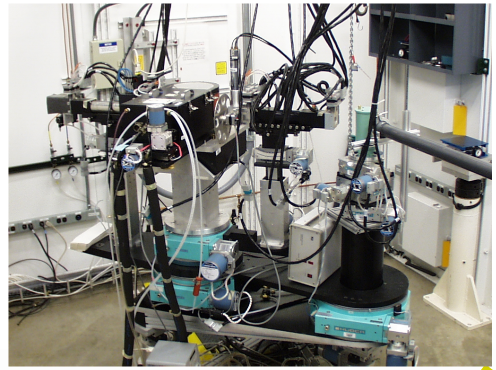

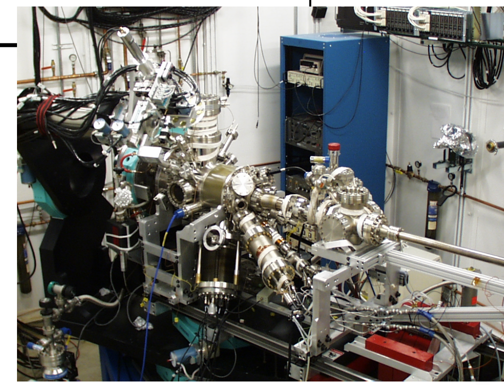

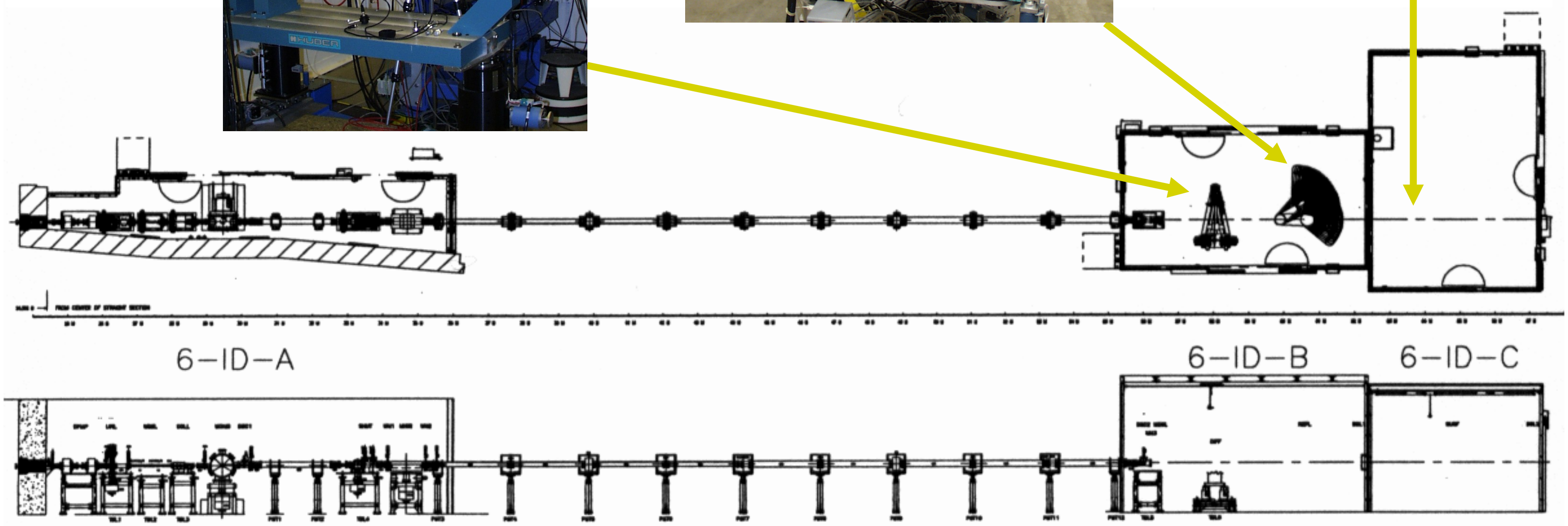

Places to go

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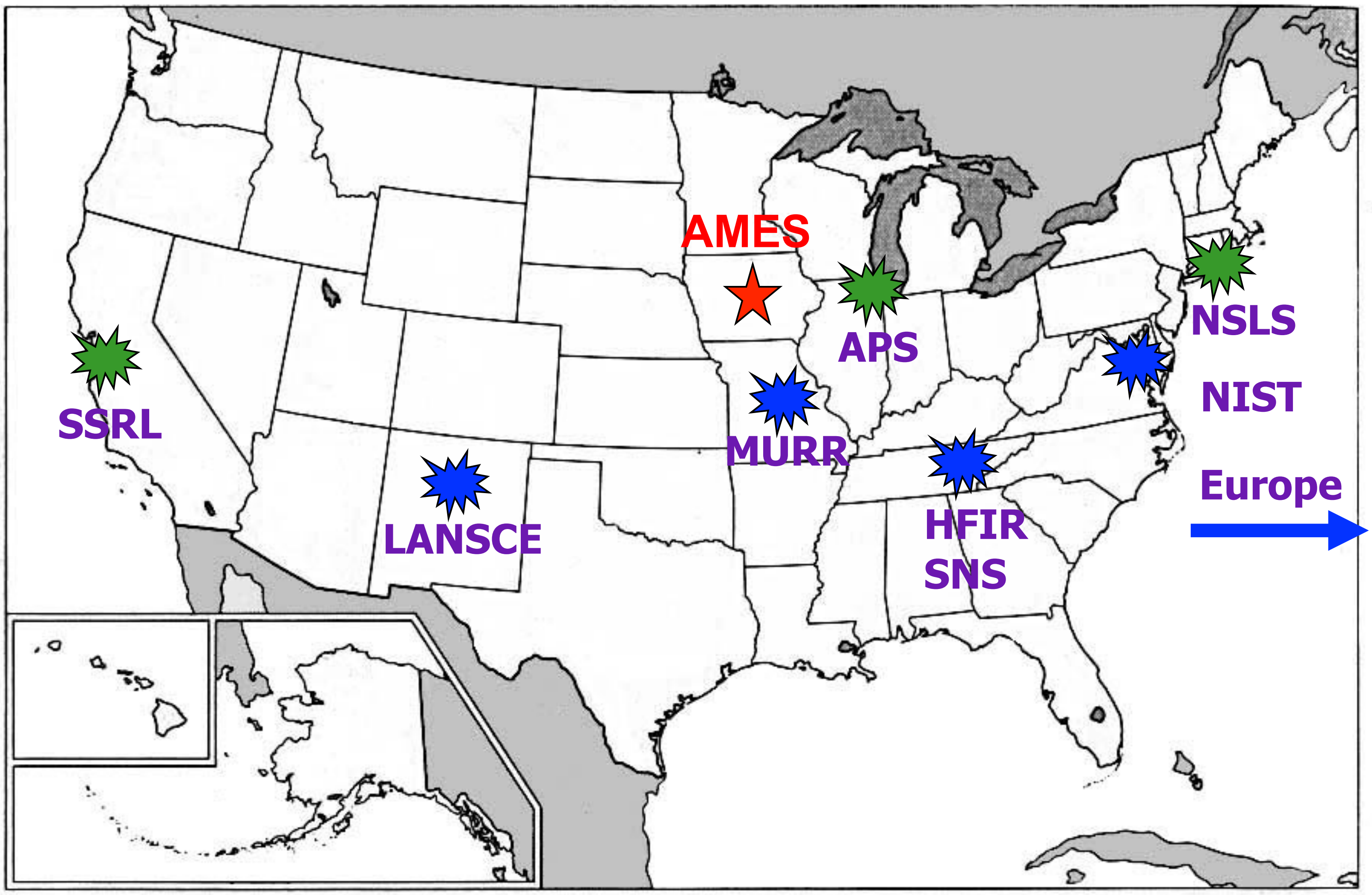

Further references

- **General neutron scattering**
  - G. Squires, “Intro to theory of thermal neutron scattering”, Dover, 1978.
  - S. Lovesey, “Theory of neutron scattering from condensed matter”, Oxford, 1984.
  - R. Pynn, http://www.mrl.ucsb.edu/~pynn/.
- **Structural refinements**
  - GSAS http://www.ncnr.nist.gov/xtal/software/gsas.html
  - FullProf http://www.ill.eu/sites/fullprof/
- **How to get beam time**
  - Talk to one of us at Ames about your experiment
  - We can identify a suitable instrument
  - Talk to instrument scientist
  - Write a beamtime request